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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking OPTOPAL Panoramic Metrology Consulting as follows: The contractor will investigate advancements to the PAL optic from earlier research (SPC 014009) which developed the design principles of a catadioptric imaging block, called the Panoramic Annular Lens (PAL). PAL delivers a 360-degree panoramic view of the 3D environment surrounding the optic. Advanced optic modeling indicated that a well-defined cylindrical volume around the optical axis of the PAL imaging block is not essential to formation of the ring-shaped panoramic image. This suggested that removal of part of the reflective coating of the concave surface around the optical axis would give a transparent view down the optical axis. A straightforward-looking optic (SFLO) mounted on the optical axis of PAL then allows an image to be displayed where no optical information is otherwise present. A rotating, inclined mirror placed in the optical axis allows steering of the SFLO to any portion of the 360-degree ring-shaped panoramic image. This is called the Humanoid PAL (or HPAL, foveated PAL) because it acts similar to human vision creating a foveal image allowing extraction of more detailed optical data.

15. SUBJECT TERMS
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Final Report

of the Project SPC 02-4039, Contract Order No. F 61775-02 WE009 entitled

"A Multipurpose Foveated PAL Optic Based on Humanoid PAL"

Introduction

1. The scope of this project as a follow-up project of the earlier works on Humanoid PAL (SPC-99-4065 and SPC-01-4009, respectively) was to design, to manufacture and to deliver to AnaLogic Computers Ltd. (in care of Dr. Akos Zarandy) a multipurpose foveated PAL optic and rotating mirror system an enhanced vision module (including the lens, the mechanical components and the program for controlling the motor that rotates the mirror) with characteristics as specified in the technical proposal.

2. The original contractor of this contract, Professor Pal Greguss passed away suddenly due to a tragic accident. His one person research&development enterprise OPTOPAL Panoramic Metrological Service is continued by his wife, Mrs. Edith Greguss - his closest co-worker and research mate during six decades - using her widows' rights with the professional help of their son, Mr. Pal Greguss, Jr., physicist, of his closest co-worker in the recent years, Mr. Janos Korniss, electrical&software engineer and research physicist in optics, and of his grand son, Mr. Tamas Greguss, electrical&software engineer. This final report was composed and the whole work was finalised by his son, Pal Greguss, Jr.

3. Reviewing his works just after his death, it seemed to us that the work necessary to complete this contract was almost ready, the apparatus being left on his workbench was waiting only the final assembly and adjustments and to forward it to Mr. Akos Zarandy's research group till 28th of April 2003. .

4. At the beginning of April there was held a meeting at AnaLogic Computers Ltd. to investigate the final fulfillment of the task. There, however, it was realized, that the arrangement being formed following the specifications of the contract and using the lens already purchased for relay optics fulfilling the specifications being undertaken didn't fit well to the ***C mount 2/3 " CCD camera*** (a DALSA product) purchased meanwhile by the recipient partner, as the original undertaking of contract was the shipping a humanoid PAL optics with a rotating mirror with a stepper motor fitting to a **C/*CS-mount ½ " CCD camera.***

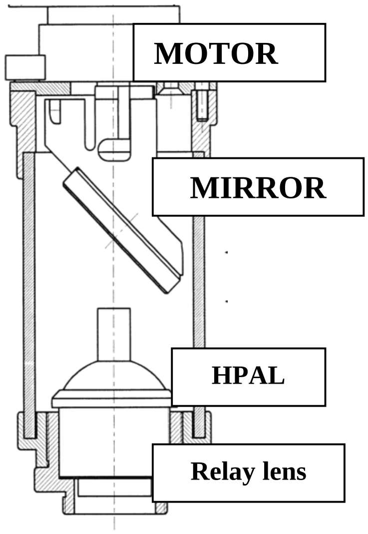
5. The above problem was overcome and it will be discussed later in details. The enhanced vision module has been delivered to AnaLogic Computers Ltd. on 28th of October, 2003. .

Summary of previous works

Feasibility studies of the projects SPC-99-4065 and SPC-01-4009, respectively, have laid down the theoretical background how centric-minded imaging (CMI) could be adapted to some military video systems. The design principles of a catadioptric imaging block, called Panoramic Annular Lens (PAL) have been outlined. PAL delivers a 360° panoramic view of the 3D environment surrounding the optic. Placing a straitforward-looking optic (SFLO) in the optical axis of PAL, on that part of the ring-shaped PAL image where otherwise no optical information is present, an image will be displayed. This version of PAL was called humanoid PAL (HPAL). Placing a rotatable mirror in the optical axis of HPAL, any predetermined portion of the 360° ring-shaped panoramic image of the 3D space can be displayed. Thus, this system acts similarly to the human vision; it creates a foveal image to be able to extract more detailed optical data. This is why this system is referred to as foveated PAL.

The proposed characteristics of the vision module to be delivered to EOARD:

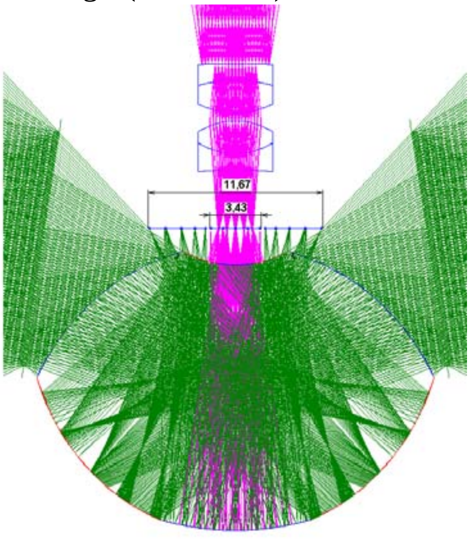
1. The diameter of the vision module will be around 40 mm.
2. The height of the vision module will be around 80 mm.
3. The vision module will use C-mount.
4. The diameter of HPAL will be around 26 mm.
5. The total horizontal viewing angle of HPAL will be around 80°.
6. The SFLO will provide about 4x enlargement.
7. The front surface mirror will be rotated by an off-the-shelf stepping motor, and will be controlled via a PC program.
8. The vision module can be adapted via C-mount to various off-the-shelf CCDs by choosing adequate off-the-shelf relay lenses.



Panoramic versus Foveal image

Since the intention with HPAL is to use a single image sensor for capturing both the 360º panoramic image (green area) and the selected foveal image (violet area), we have to know the pixel area ratio of these two pictures.

The surface area of the image sensor covered by the panoramic image is about **3.37** times bigger than that of the foveal image. Anyone should always keep this fact in mind when a camera is chosen for a given task. This is especially true when a system includes a CNN-UM focal plane array processor chip.



As for an example in the case of an *IBIS5 1.3 Mpixel CMOS Image Sensor*, where the resolution and pixel size result in a 2/3” optical format, the 360º panoramic image will cover about 535,753 pixels of 6.7 µm x 6.7 µm size, while the foveal image will occupy around 226,056 pixels of the same size.

Consulting with A. Zarandy of *AnaLogic Computers Ltd.* we have learned that a new CNN-UM focal plane array processor chip with higher resolution is still not available and, therefore, they are looking for a CMOS camera capable of shooting at least 1000 frames/sec.

Since then we were notified that *AnaLogic Computers Ltd.* has purchased an *IBIS5 Dual Shutter Mode 1.3 Mpixel CMOS Image Sensor* and a *DALSA camera*.

The features *of this image sensor and camera* ***relevant to our task*** *are that they have optical format of* ***a 2/3” and C mountable*** *fittings. From other sources you can see that recently the trend of the development of the high resolution CCD cameras is to increase the optical format instead of decreasing the pixel sizes.*

Elements of the vision modul connected to the CCD camera

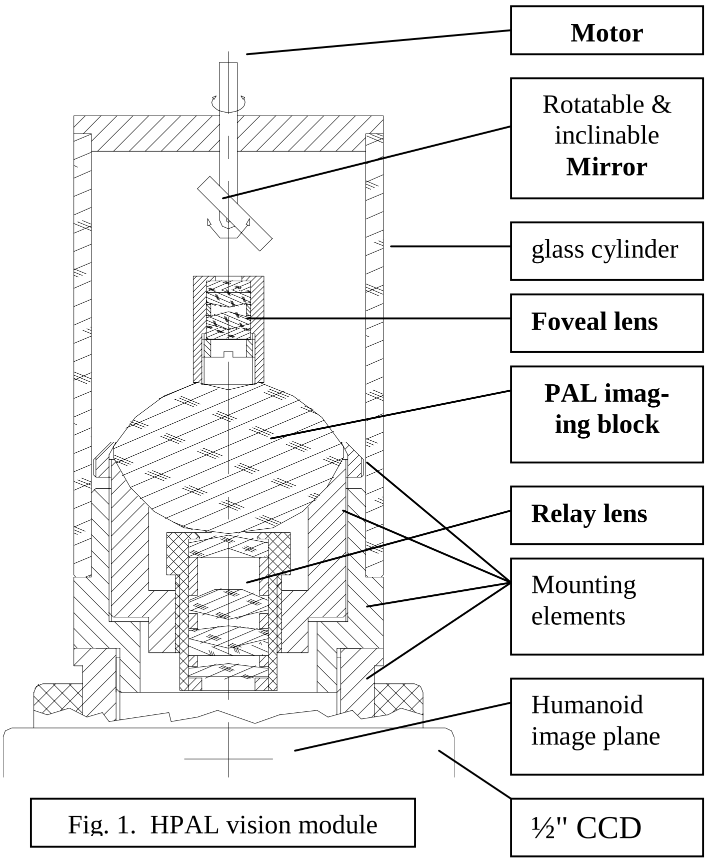
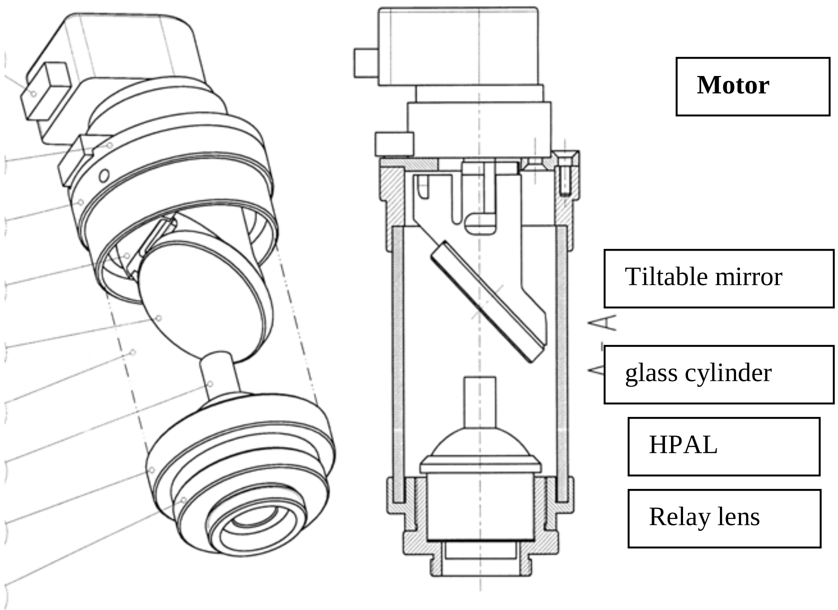


Fig. 1. HPAL vision module

There are four structural elements: motor, mirror, HPAL, relay lens.

*The first structural element is the **Stepper Motor***

To rotate the front surface mirror we chose a *stepper* motor that is not as sophisticated as the US-motor we used in our preliminary experiments reported in SPC 01-4009, however, it weighs less, which makes it easier to move HPAL from one camera type to another. Nevertheless, this motor as well is controlled via a software we developed.



As it can be learned from its control panel shown below, not only the *rotating direction* of the inclined mirror can be chosen at will, one can also select in advance the *direction of the foveal view*; determine the *stepping rate* of the mirror with variable inclination; etc.

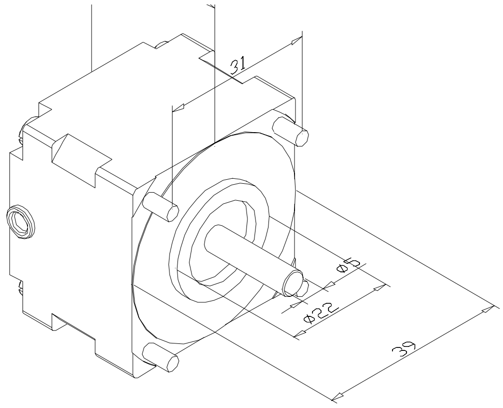
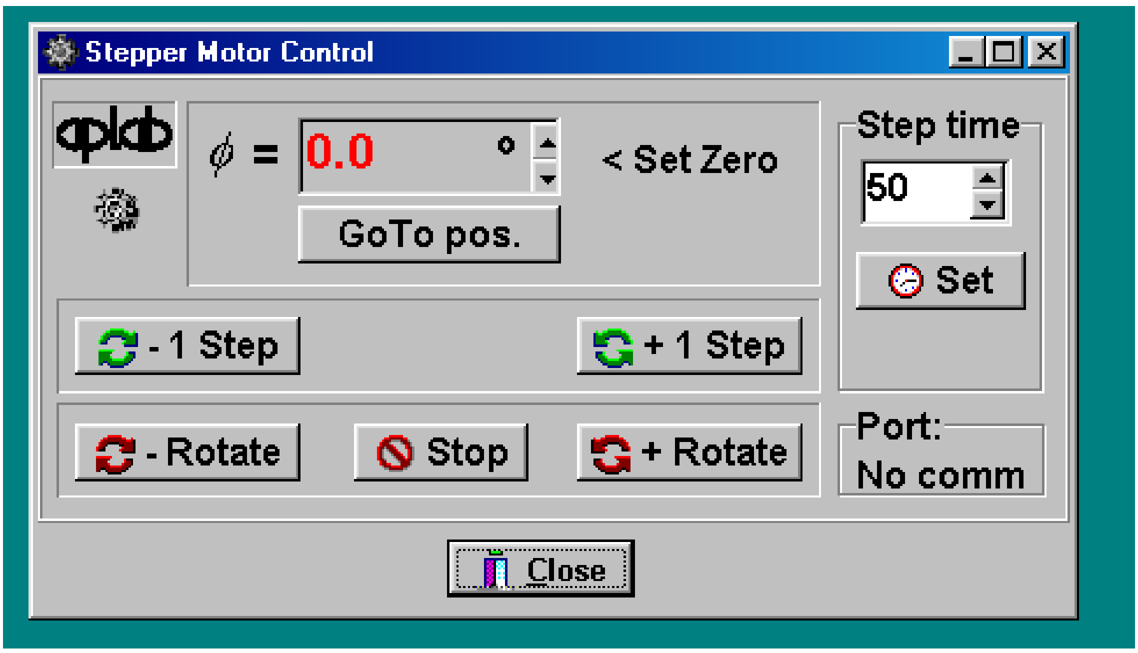


Fig. 2. The stepper motor



The second structural element is the rotatable and tiltable front surface mirror.

To be able to select from the 360° panoramic view any foveal image direction at will, the rotating front surface mirror has to have a mount that allows changing the mirror inclination angle with respect to the optical axis of the system.

Fig. 3. The inclination angle may be changed using screws in this hole and another one in a hole on the other side

The third structural element is the ***HPAL Humanoid Panoramic Annular Lens****, consisting of two parts: the PAL imaging block itself and the foveal lens system*

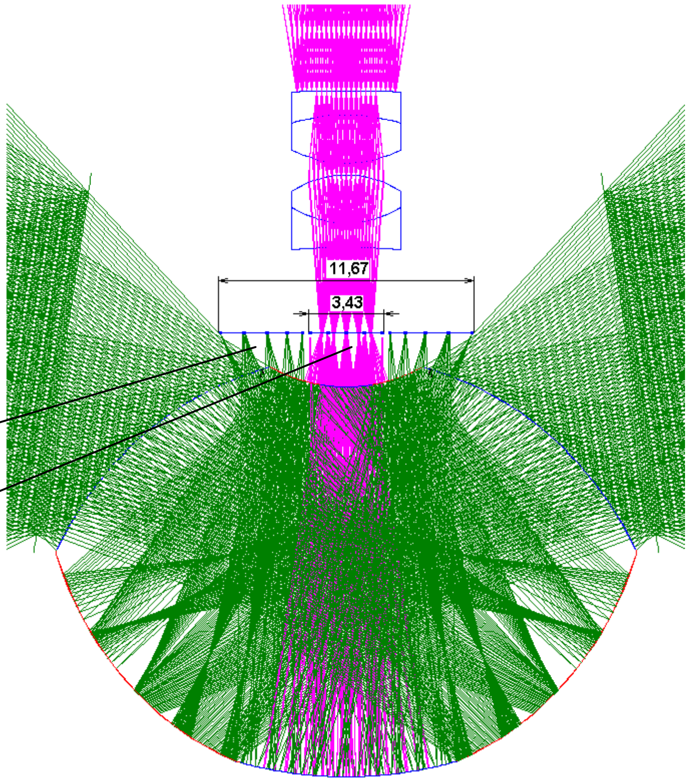
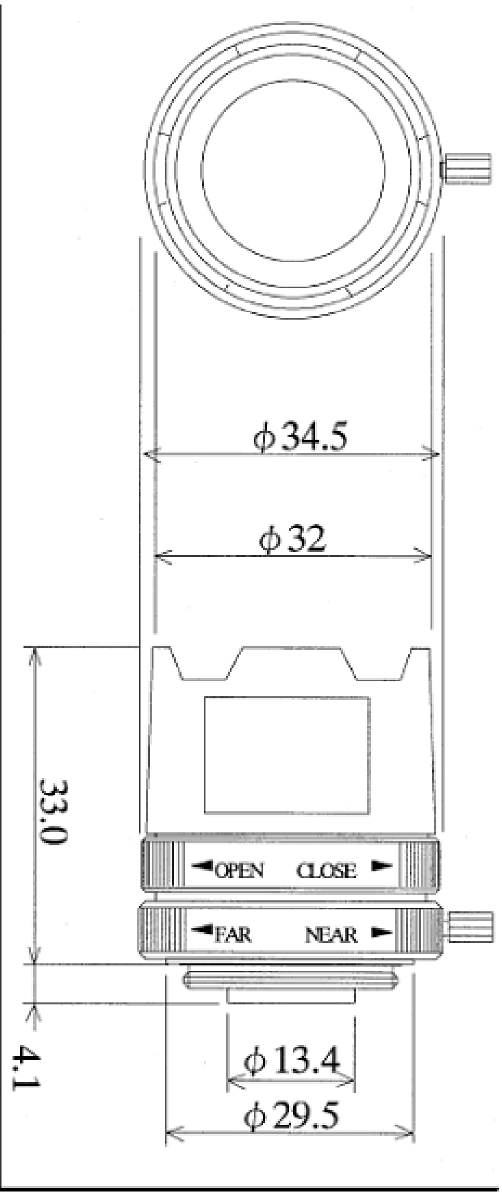


Fig. 4. The virtual images formed by the PAL block (annular part), and by the foveal lens (central part) in one common image plane

The fourth structural element is the ***relay lens system***

The role of the relay lens is to form a real image in the required size in the plane of the sensor. There are a lot of suppliers offering quite a wide range of the video optics, but it is not easy to select the most appropriate ones for imaging the PAL virtual image to a sensor of a CCD camera and, at the same time, which is compact enough.

Earlier the so-called finite conjugate micro video lenses seemed to be ideal for close proximity applications in confined areas. Thus, we purchased some of them from Edmund Industrial Optics (Barrington, New Jersey); some from other companies. Unfortunately, our expectations to get images of appropriate quality have not been realized. The explanation is simple: their effective diameters, their aperture, are too small to collect enough image forming rays of PAL imaging block. You have to be aware of the fact that not the whole PAL block takes part in forming an image portion of the annular image, as we learned about the common imaging systems.

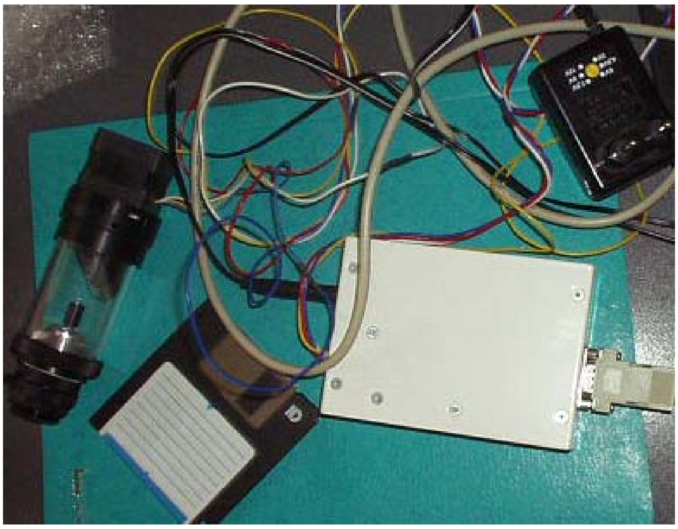


Later we wanted to try Schneider Compact VIS-NIR Lenses, which were described in Edmunds Catalog 2003. (Page 224.). Against our expectations these lenses did not provide us the necessary image size.

Then, finally, we have found the Computar H1214FI lens with focal length of 12 mm, with manual iris (1:1.4) and far – near focusing capability. Its mechanical dimensions permit to fit the lens into the glass cylinder which connects the camera parts of the vision module to the rotatable mirror part. To be able to do this we had to modify the Computar lens assembly in such a way, that the upper housing was removed and was replaced with a new mounting element; similar to that developed by Professor Greguss in his preliminary experiments described in a previous project and reported in Final Report of SPC 01-

4009.
(see Fig 1. of this report).

The enhanced vision module (including the lens, the mechanical components and the program for controlling the motor that rotates the mirror) with characteristics as specified in the technical proposal was delivered to AnaLogic Computers Ltd. (in care of Dr. Akos Zarandy) at the address:
AnaLogic Computers Ltd.
13-17 Kende Str.
Budapest
H1111
Hungary
Phone: +36 1-209-5400
on October 28, 2003.



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Edith M. Greguss (Dr. Pál Greguss' successor) Pál Greguss, Jr.

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